

A COLOR SCHLIEREN SYSTEM

Technical Report No. 105-ME-F

by

Thomas J. Kessler
NASA Trainee in Mechanical Engineering

and

William G. Hill, Jr.
NSF Fellow in Mechanical Engineering

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Rutgers - The State University
College of Engineering
Department of Mechanical Engineering
New Brunswick, New Jersey 08903

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ABSTRACT

Details are presented on a color Schlieren system being developed to aid in the analysis of complex compressible fluid flows. This system requires only small modifications to conventional Schlieren systems and provides excellent results. Several photographs comparing black and white with color results are presented.

INTRODUCTION

The development of the color Schlieren system described in this paper was undertaken in conjunction with studies of separated compressible fluid flows being carried out in the Emil Buehler Supersonic Wind Tunnel in the Department of Mechanical Engineering. The various separation and reattachment phenomena under study often become quite complicated as compared with the inviscid aerodynamic phenomena usually investigated by optical methods. Because of this complexity, some difficulty is encountered in interpreting conventional Schlieren photographs.

It is felt that the use of a color Schlieren will aid interpretation of the observed phenomena, particularly in identifying regions of gradual compression or expansion. Since the eye seems to be more sensitive to changes in color than to changes in shades of gray these regions will stand out in a color Schlieren picture much better than they would

when using the conventional black and white Schlieren. These anticipations have been fulfilled by the present system and these color Schlieren techniques may prove useful in many other applications. However, using a color Schlieren system does have some disadvantages. Namely, it is expensive to reproduce color photographs, and technical journals only publish black and white photographs.

Standard compressible fluid flow literature, for example references 1, 2, and 3; contain the basic theory and details of many possible Schlieren devices. The principles of operation of conventional Schlieren systems will therefore only be briefly reviewed here for convenience.

CONVENTIONAL SCHLIEREN SYSTEM

The basic Schlieren system in use at Rutgers is of the standard Toepler type, utilizing a mercury vapor light source and off-axis parabolic mirrors. This system is shown in Figure 1. The light from the source is focused through a slit which lies in the focal plane of the first parabolic mirror. This mirror then focuses the light into a parallel beam which is passed through the glass walled test section. Light which passes through regions of uniform flow will be undeflected (solid lines) and will emerge from the test section in a parallel beam. It is then focused into an image of the slit source at the focal plane of the second parabolic mirror.

A knife edge is inserted at this focal plane so that it intercepts about one-half of the source image when the flow is uniform. Light which encounters density gradients normal to the light direction within the test section will be deflected (dotted lines), and hence will not be focused into the image of the slit source. The image of an object in the test section is brought to focus in the camera by an external lens as shown.

Details of the operation of a conventional Schlieren system are shown in Figure 2. Figure 2a shows undisturbed light rays converging to form an image of the source at the knife edge. For maximum sensitivity, the knife edge is adjusted to cut off approximately one-half of the light from the source thus giving a uniformly gray image on the film. Density gradients in the flow could cause refraction of light rays as shown by the dotted lines in Figure 2b and 2c. The refracted rays of Figure 2b miss the knife edge entirely thus causing a bright white illumination of the upper part of the film. Figure 2c shows just the opposite case of refracted rays being blocked off completely by the knife edge, causing a dark black image on the upper half of the film. If the density gradients were such that the light rays were refracted parallel to the knife edge, no change in illumination would occur at the film. A Schlieren system is only sensitive to density gradients having a component normal to the knife edge.

COLOR SCHLIEREN

To achieve a color Schlieren system, the conventional knife edge is replaced by a tri-color filter. The use of a tri-color filter to obtain color Schlieren was chosen as a variation on one of the many possible schemes suggested in reference 3. More recently this tri-color technique has been suggested in reference 4. The materials used in the construction of the filter are cellulose acetate filter sheets which are normally used for coloring spot lights and other theatrical work.

The material, which is approximately 0.010 in. thick, is cut into strips of the required size and then mounted on a frame, see Figure 3. The center section is approximately equal to the width of the slit image, about 0.020 in. The present method of construction is to cut the filter sheets with ordinary scissors, but some scattered light is encountered due to the ragged edges. A better method of obtaining smooth joining edges is being sought.

Figure 4 shows the details of operation of the present color Schlieren system using a red-blue-yellow filter. The undisturbed light rays of Figure 4a all pass through the narrow blue slit placed at the image of the light source. This results in a uniform blue illumination of the film. When a disturbance is present causing refraction of some light rays (dotted lines) one gets changes in color on the film image.

Figure 4b shows light rays refracted so that they pass through the yellow filter. This results in a yellow image coloring the top half of the film. Figure 4c shows light refracted in the opposite direction so that the refracted rays now pass through the red filter thus causing a red image on the top half of the screen.

During the development of the present system, many different color combinations were tried. The present set was chosen as offering the best appearance and discrimination by eye using direct observation of the image on a screen. It is possible that the color sensitivities of color films will dictate a change in the color choice, but present indications are that the red-blue-yellow combination is also the best photographically.

Various other modifications were also tried such as allowing the central section to be open to white light, as discussed in reference 4, or blocking off the central section completely. The results of these trials were unsatisfactory and led to the rule of thumb that all three color filters should have approximately the same transparency. Another modification tried, also unsatisfactorily, was the use of a two color filter with the image of the light source passing half through one color and half through the other.

RESULTS

Excellent results have been obtained using the color Schlieren system with both 35 mm. still photographs and 16 mm. high speed motion pictures (see reference 5). Both photographic applications employ an auxiliary lens placed after the knife edge to refocus the test section image in the plane of the film. Since the original camera lenses are removed in this application, there are no "f" stop settings for exposure adjustment. Instead the source slit width is adjusted to vary a reflected light meter reading taken on a standard white card placed in front of the camera. Correlating these light meter readings with results enables one to determine the card light meter reading for proper exposure at a given shutter speed and for a given film ASA number.

The 16 mm. high speed motion pictures were taken at exposure times varying from 0.0001 seconds to 0.0005 seconds, depending upon slit width and frame rate. The maximum frame rate used so far is 7000 frames per second. A commercially available 16 mm. high speed motion picture film with an ASA rating of 200 has given excellent results. Details of color motion pictures used in the analysis of unsteady supersonic flow phenomena clearly show the advantage of using a color Schlieren over the conventional black and white system.

Exposure times for 35 mm. photographs vary from 0.002 seconds to 0.005 seconds depending upon source slit width

and film ASA number. Excellent results have been obtained using commercially available 35 mm. color film with ASA numbers from 25 to 50.

Figures 5 through 7 are examples of 35 mm. photographs taken using both the color Schlieren and a conventional Schlieren system. Both the black and white and the color photographs were taken with the same exposure (0.002 seconds) and using the same film (commercially available color film of ASA 25) so that the use of a different film would not affect the results. The knife edge is horizontal for the black and white photographs and the blue filter is horizontal for the color photographs.

A 0.75 in. diameter space capsule model at Mach 2.5 in air is shown in Figures 5a and 5b. The recompression region where the separated flow about the capsule is turned to an axial direction on the sting support is seen to be more distinct in the color photo (Figure 5b) than in the black and white photo (Figure 5a). Figures 6a and 6b show Mach 2.5 flow over a 0.25 in. diameter cone cylinder model with a one inch diameter afterbody. Details of the separation region ahead of the large diameter cylinder are much clearer in the color photographs (Figure 6b). Mach 2.5 flow over a 60° included angle cone with a notched surface is shown in Figures 7a and 7b. Expansion and recompression regions are thoroughly detailed in the color photo (Figure 7b) while the black and white photo (Figure 7a) lacks sensitivity for satisfactory

study of these regions.

The above photographs indicate how a color Schlieren can show more details of the flow structure than a conventional Schlieren system. For more complicated separating and re-attaching flows with accompanying viscous effects, the color Schlieren system becomes increasingly valuable. Without the added sensitivity of the color system, many details of these complex flows would go unobserved.

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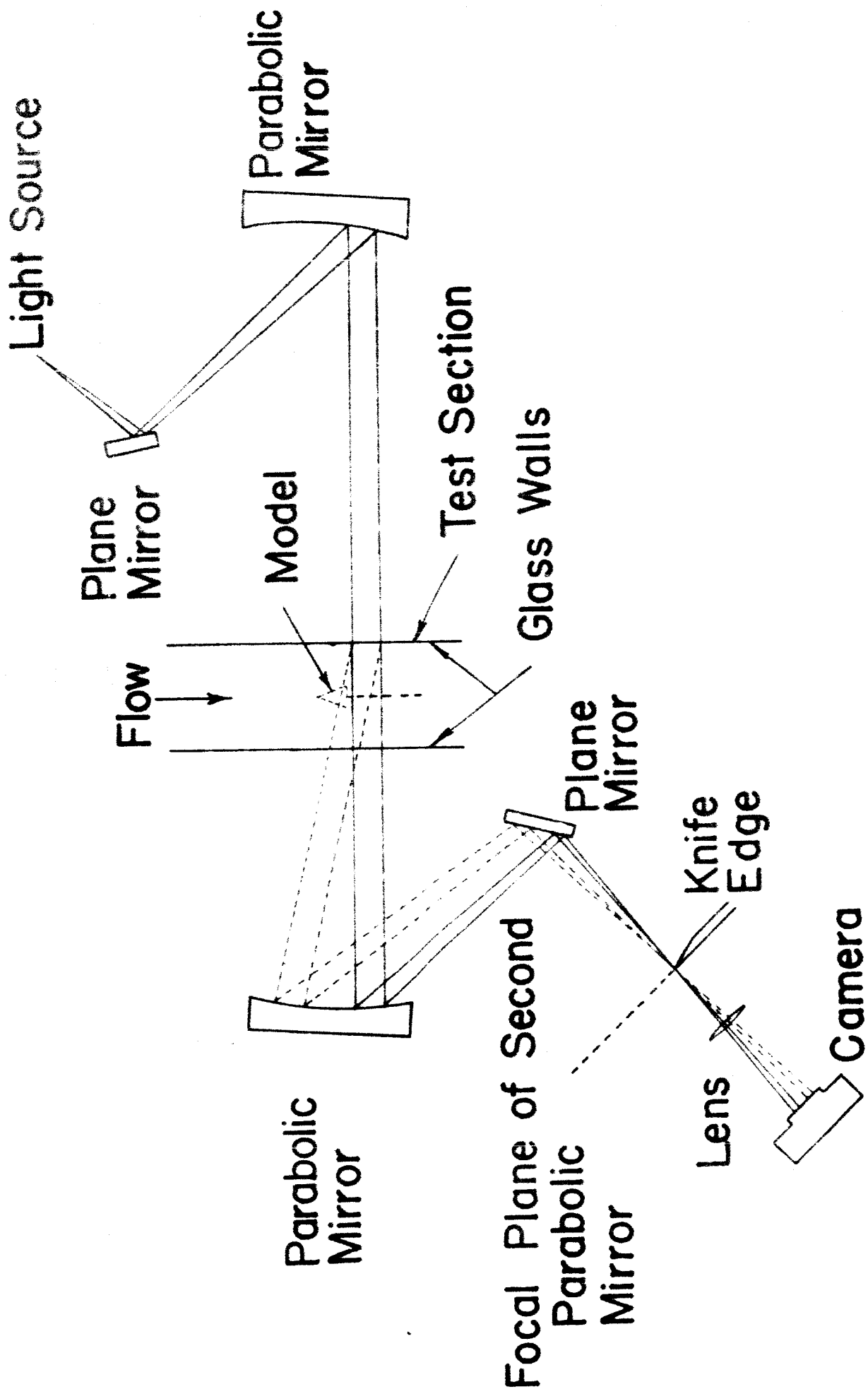


Figure 1 - Conventional Schlieren System Schematic

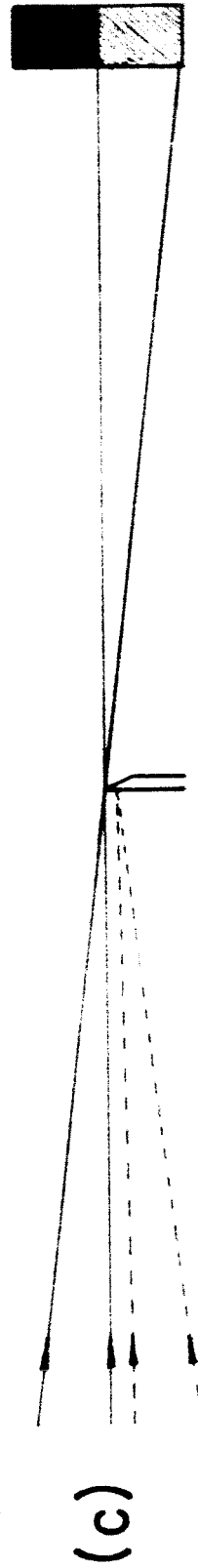
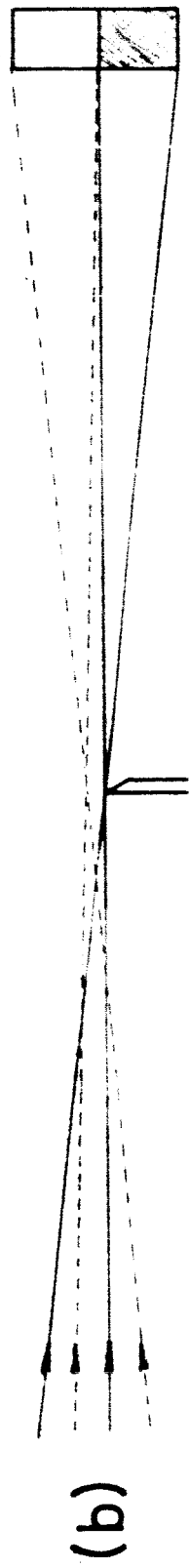
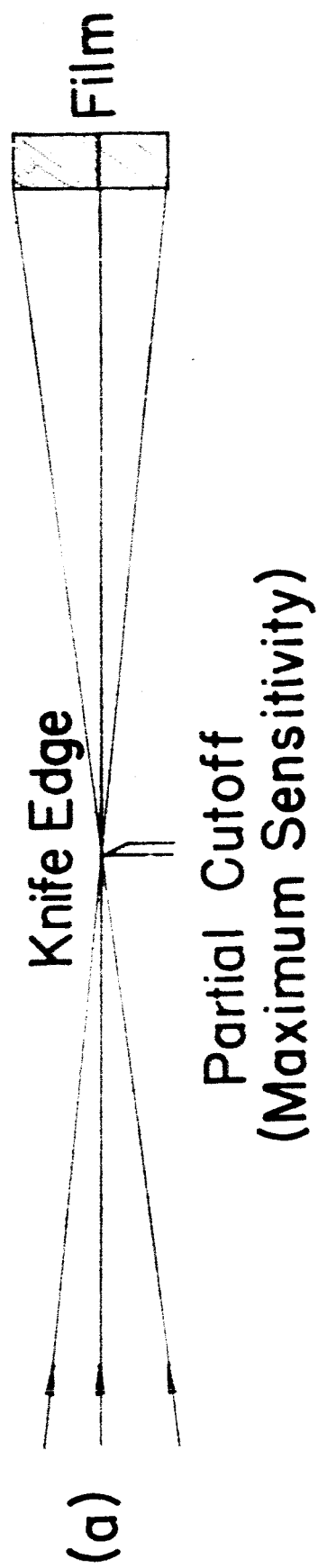


Figure 2 - Refraction Pattern for Conventional Schlieren System

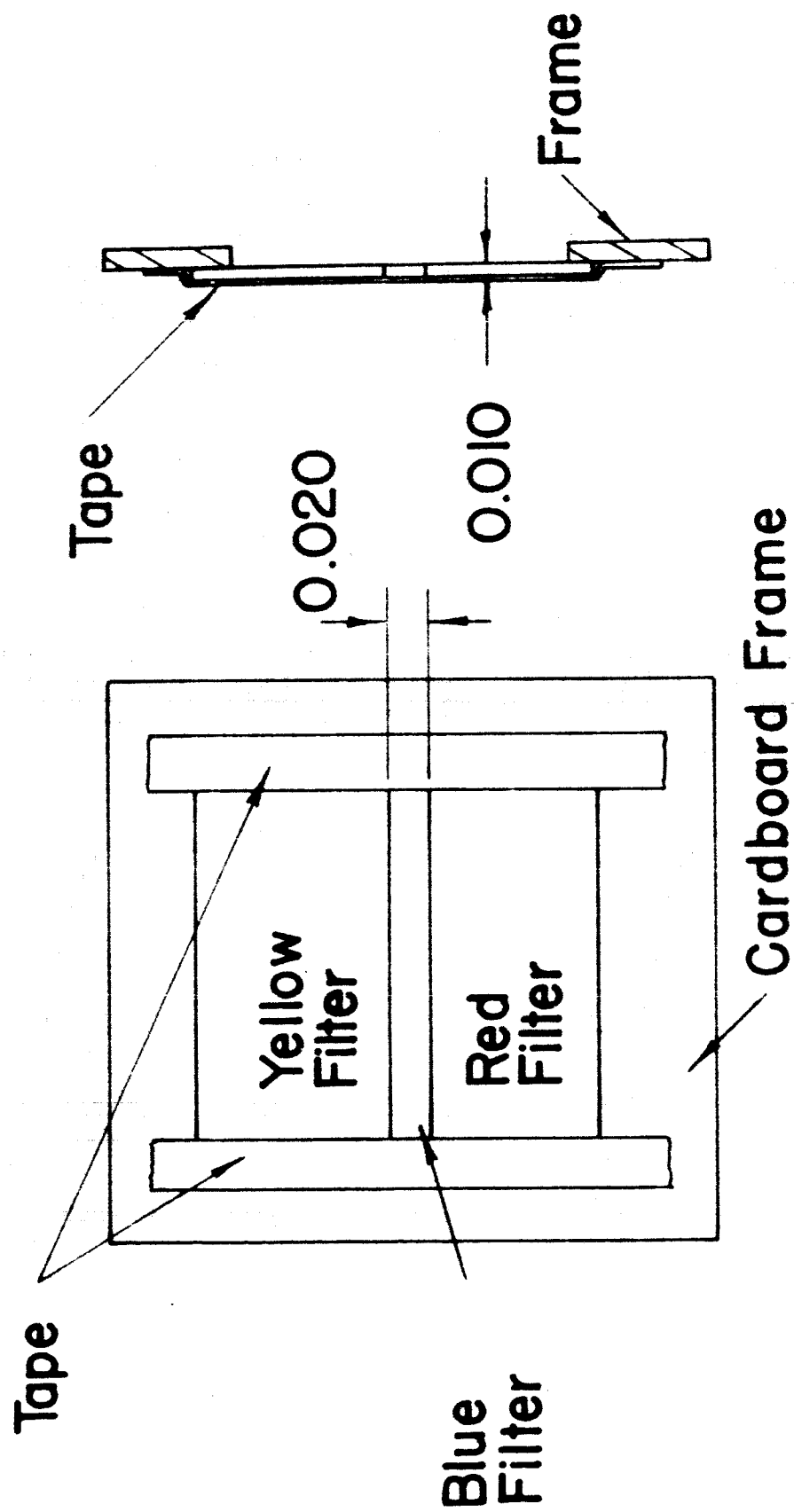


Figure 3 - Construction of Tri-Color Filter

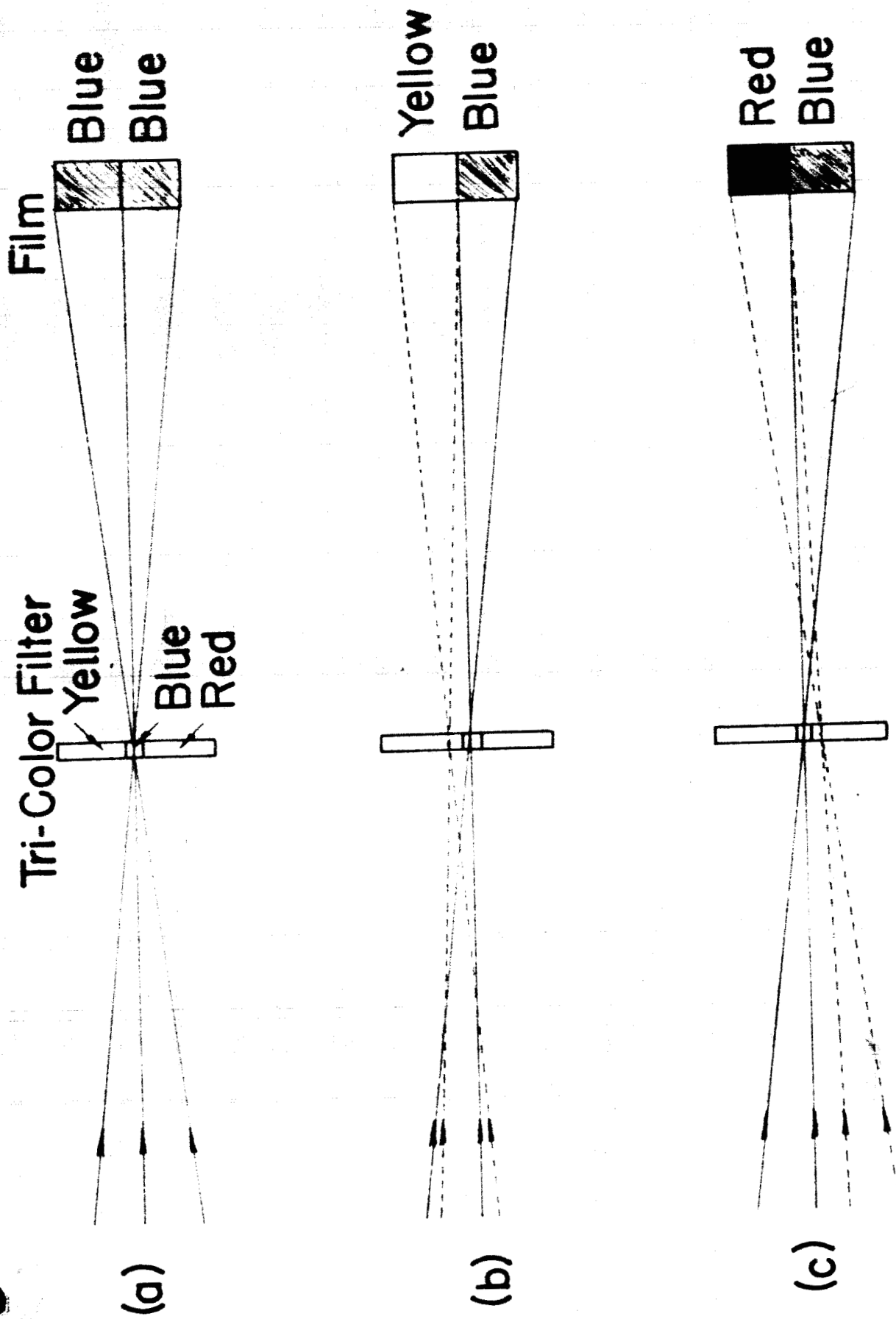
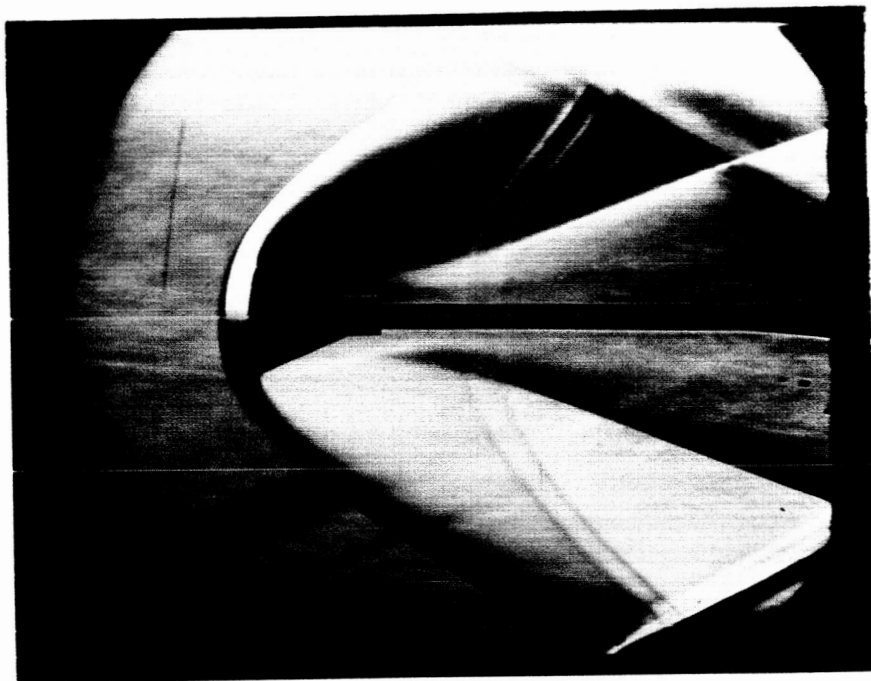
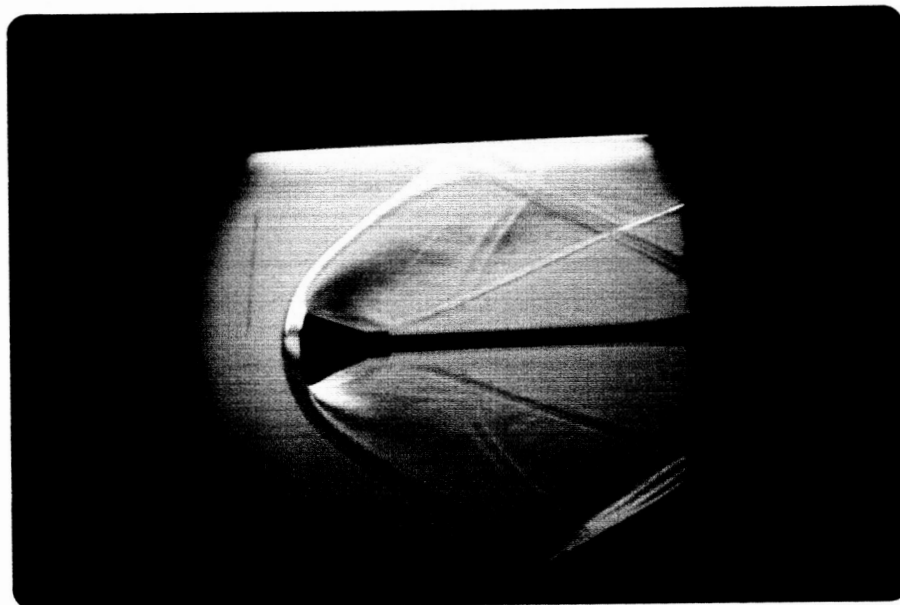


Figure 4 - Refraction Pattern for Tri-Color Schlieren System

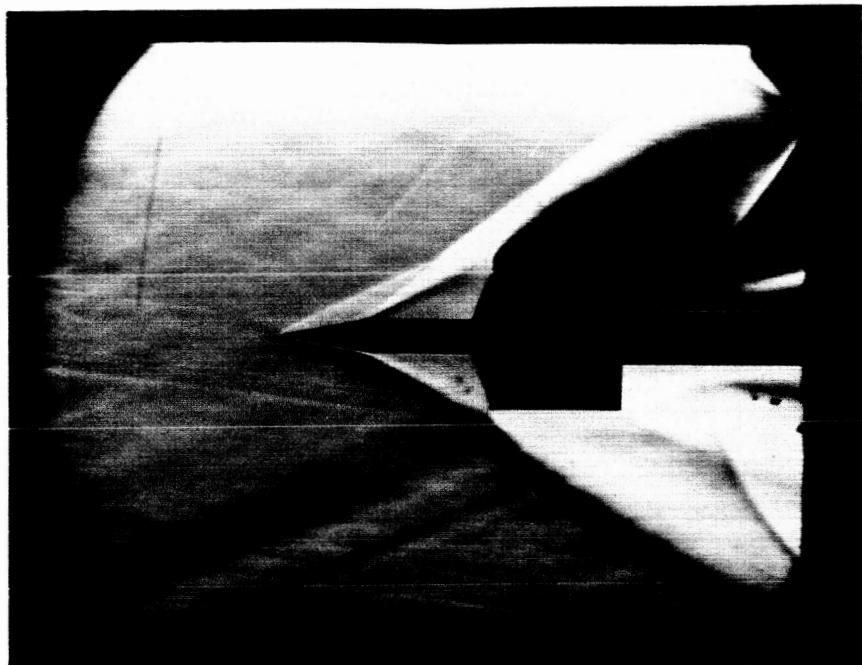


(a)



(b)

Fig. 5. Mach 2.5 Air Flow about a 0.75 Inch Diameter Space Capsule Model

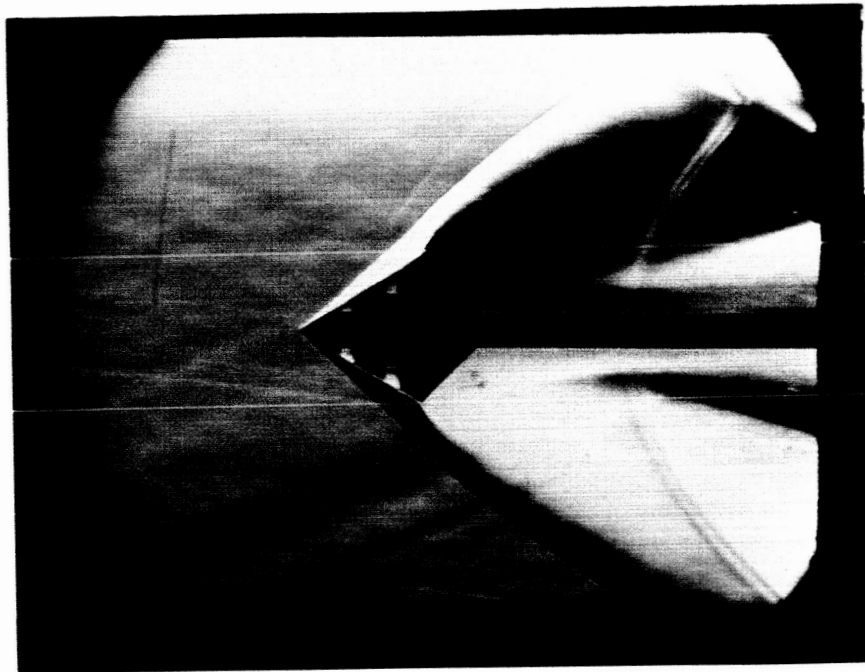


(a)



(b)

Fig. 6. Mach 2.5 Air Flow about a 0.25 Inch Diameter Cone
Cylinder Model with a 1.0 Inch Diameter Afterbody



(a)



(b)

Fig. 7. Mach 2.5 Air Flow about a 60° Included Angle Cone with a Notched Surface